

# METAL ENRICHMENT AND ENERGETICS OF GALACTIC WINDS IN GALAXY CLUSTERS

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We investigate efficiency and time dependence of metal enrichment processes in the Intra-Cluster Medium (ICM). In this presentation we concentrate on the effects of galactic winds. The mass loss rates due to galactic winds are calculated with a special algorithm, which takes into account cosmic rays and magnetic fields. This algorithm is embedded in a combined N-body/hydrodynamic code which calculates the dynamics and evolution of a cluster. We present mass loss rates depending on galaxy properties like type, mass, gas mass fraction and the surrounding ICM. In addition we show metallicity maps as they would be observed with X-ray telescopes.

## 1 Introduction

From X-ray spectra it is evident that the ICM contains metals (Fukazawa et al. 1998). As heavy elements are only produced in stars the processed material must have been ejected by cluster galaxies into the ICM. Possible transport processes are ram pressure stripping (Gunn & Gott 1972), galactic winds (De Young 1978), galaxy-galaxy-interactions or jets from AGNs. In this work we concentrate on the effects of galactic winds. The mass loss rates due to galactic winds are calculated taking into account the galaxies properties. The ejected material acts as an input for our combined N-body hydrodynamic code which calculates the redistribution of the material due to the evolution of a galaxy cluster. The properties of the galaxies are obtained by applying seminumerical galaxy evolution models.

## 2 The combined N-body Hydrodynamic Code

Large-scale structure formation is simulated with a  $\Lambda$ CDM N-body tree code with an additional semi numerical model for galaxy formation (van Kampen et al. 1999). The gas is treated with a PPM (piecewise parabolic method) hydrodynamic grid code (Colella & Woodward, 1984). To obtain high resolution in the cluster center the hydrodynamic code uses a fixed mesh refinement (Ruffert, 1992). The simulations are covering a volume of  $20 (h^{-1})$  Mpc $^3$ . In addition four nested grids each with the same resolutions are calculated to obtain the highest resolution in the center (Fig.1).

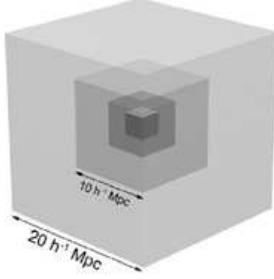


Figure 1: The fixed mesh refinement in our hydrodynamic simulations

## 3 The Galactic Wind Algorithm

The mass loss rate due to supernova driven galactic winds is calculated with a code developed by Breitschwerdt et al. (1991). The algorithm calculates for a given galaxy the mass loss rate and wind properties like the velocity of the ejected matter as a function of distance to the galaxy or the pressure flow. As an input for the wind code galaxy parameters like halo mass, disc mass, spin parameter, scale length of the components, temperature distribution of the ISM, magnetic field strength and density distribution as well as stellar density distribution are required. All those properties are calculated within the semi numerical model for galaxy evolution. In order to save computing time we performed parameter studies. The results are summarised in a look up table. One example of such a table is shown in Fig. 2. The mass loss rate is plotted as a function of the spin parameter and the mass of the disc. In this example the halo mass of  $3 \times 10^{11} M_\odot$  is assumed to be constant for all model galaxies.

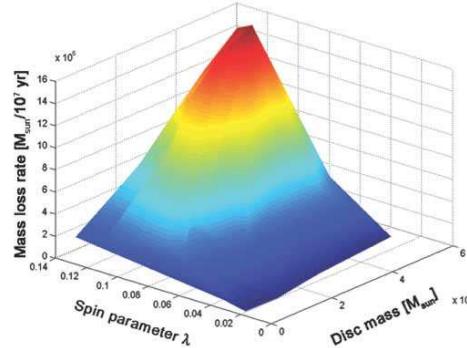


Figure 2: Mass loss rate as a function of disc mass and spin parameter for a given constant halo mass of  $3 \times 10^{11} M_\odot$ .

The larger the disc mass and the spin parameter the higher is the mass loss rate. The extent

of the disc increases with increasing spin parameter and therefore the probability for supernova explosions at large radii increase as well.

#### 4 First Results

We then applied the galactic wind tables to our combined N-body hydrodynamic code with semi numerical galaxy evolution. The model cluster consists of 1850 galaxies total of which 338 galaxies show a wind. The overall average mass loss rate due to galactic winds is about  $25 M_{\odot}/\text{yr}$ . Note that starburst galaxies were not taken into account. The mass loss rates together with the metallicities of the galaxies act as an input for the hydrodynamic code. The code calculates the dynamics of the ICM and hence can simulate mixing of the ejected matter and the ICM due to a cluster merger process. In figure 3 the temperature distribution projected along the line of sight the model cluster is shown before and after the cluster merger. Due to the merging process several outgoing shockwaves can be seen. The time between the two images is about 4.9 Gyrs in a  $\Lambda$ CDM cosmology, with  $\Omega_{\Lambda} = 0.7$ ,  $\Omega_m = 0.3$ ,  $h_0 = 0.7$ , and  $\sigma_8 = 0.93$ .

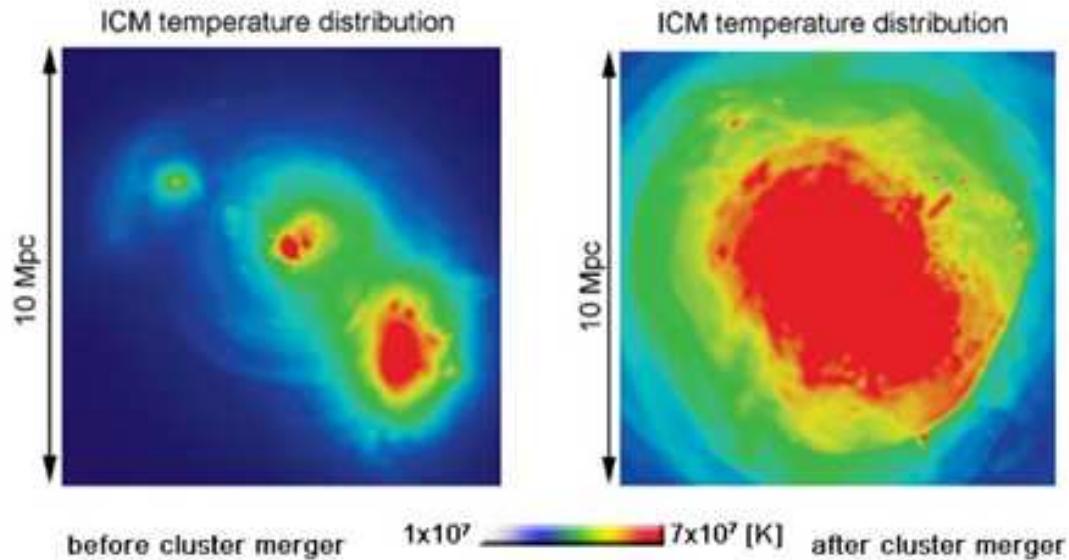


Figure 3: Projected temperature distribution of our simulation cluster. Left image before merger right image after merger.  $\Delta t = 4.9$  Gyrs.

In figure 4 the ejected matter due to galactic winds and the mixing with the ICM due to the merger is shown. In the upper panel a 3D distribution of the metallicity of the ICM in a  $10 \text{ Mpc}^3$  cube is displayed, that has been accumulated since  $z=1$  by galactic winds. In the central  $5 \text{ Mpc}^3$  cube the mixing of the ejected material with the ICM is more efficient than in the outer regions of the cluster. As the density of the ICM increases towards the cluster center the winds will be suppressed within a region of several 100 kpc around the center. In the outer regions of the cluster where the density decreases galactic winds are more efficient to enrich the ICM than ram pressure stripping (see Dominko et al. this volume).

#### Acknowledgments

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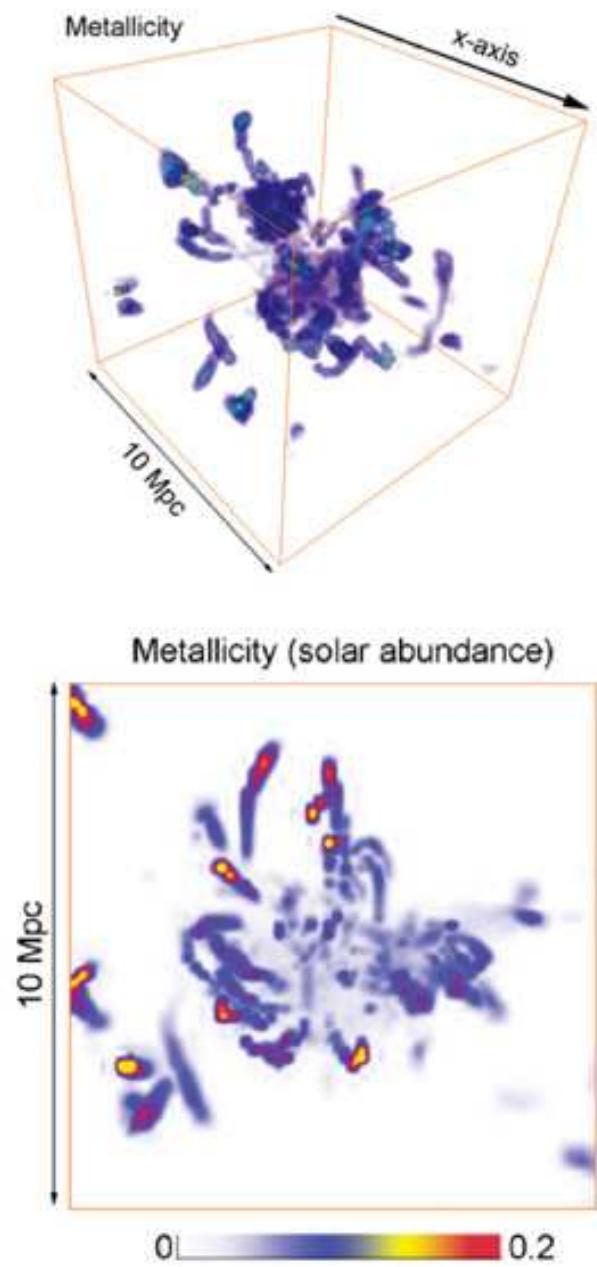


Figure 4: Metallicity map of a simulated galaxy cluster. Top: 3D distribution. Bottom: metallicity map projected along the x-axis.